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INFLUENCE OF TOWER DESIGNS ON TRANSMISSION-LINE LIGHTNING PERFORMANCE

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ABSTRACT

The latest nanosecond geometrical modeling techniques to measure transmission-tower lightning response are briefly reviewed. Tests on three different tower designs are reported which show the influence of tower geometry on insulator lightning voltages. Tower shielding angles and midspan flashover phenomena are included.

INTRODUCTION

The actual geometry of transmission-line towers often has an effect on line lightning performance as significant as the line insulation level itself. This effect comes about in several ways: by drawing lightning to the line because of the line height above the ground, by generating an electromagnetic component of voltage across the tower insulators, and by the tower geometry controlling the probability of shielding failures. Sometimes by relatively minor modifications of tower geometry, the line designer can make a substantial improvement in lightning performance. It is the purpose of this paper to review some of these effects, to show how one tower design can be compared to another by new modeling techniques, and how present-day computer techniques can be applied to the problem.

NEW MODELING MEANS OF COMPARING TOWERS

A significant step forward in evaluating the lightning response of transmission towers was taken in 1959[1] with the development of nanosecond geometrical tower modeling techniques. This technique employed a 50:1 geometrical scale model of each tower to be studied, complete with all phase conductors and ground wires scaled to size and with footing resistances installed. Miniaturized lightning currents were injected into the tower top or on the ground wires or phase conductors, and the voltages created across the tower insulators observed oscillographically. Since Maxwell's field equations applied equally to both model and full-scale tower, one could, by proper attention to time and distance scaling, determine the full-scale tower response by model measurements.

Since 1959, tower model measurements have undergone great improvement. Figure 1 shows a modern 50:1 scale tower model undergoing test in the High Voltage Laboratory. A specially-modeled lightning stroke injects a model stroke current into the tower top. This stroke model, wound as a distributed inductance and capacitance, simulates both the pilot streamer and the return stroke, including a return-stroke velocity of about one-third the velocity of light. The spines visible on the stroke body simulate corona streamers and add extra capacitance to the channel for charge storage. In use, the stroke channel is first charged up through a dc supply in the same manner as a charged pilor streamer. Then, at time zero, the stroke is connected to the tower through a miniature mercury switch. The stroke then discharges into the tower top, and measurable voltages appear across the insulator strings.

In the original modeling techniques[1] a variety of stroke current wave shapes were injected into the tower or ground wires, and the insulator voltages measured for each. However, the technique has gradually improved to the point where a good-quality unit-function current wave shape can be utilized. By

measuring the insulator voltage response for a unit-function current applied, the voltage for any other current wave shape can be calculated quite simply by a digital evaluation of a convolution integral. This has greatly simplified the measuring process and speeded up the acquisition of data without sacrificing precision.

A TOWER COMPARISON

Figure 2 shows three representative 345-kV transmission towers arranged for a model study. Each has two shield wires and is strung with a single circuit. The same unit-function lightning current was injected into each, and the voltages developed across the insulators in each phase for each tower are given in Fig. 3. Tower C has the poorest response. Not only does it have the highest voltage, but the duration of the voltage is greater. In general, the taller and thinner a tower becomes, the greater will be the insulator voltages. Conductor 1 of Tower C has the highest inducted voltage, but also has excellent coupling to the two ground wires. If there were only one ground wire the voltage would be over 50 percent greater.

Figure 4, measured on Model B of Fig. 2, shows how the voltage across a tower insulator string changes as the location of the stroke changes between tower and midspan. These results are important in making lightning-outage calculations.

Figure 5 presents a sample conversion of the model data just described for Tower B into curves of insulator voltages per ampere of stroke current for ramp-function current waves having different times to crest. These computed curves are derived from the unit-function response.

Data of the type displayed in Fig. 5 can be inserted into a digital computer program called "LICAL3" to compute line-outage performance. The output from this program is in the form of experience tables, enabling one to weigh the consequences of alternative choices and to obtain the best lightning performance per dollar invested (see Fig. 6). One of the recent projects sponsored by the Edison Electric Institute included the preparation of design curves from such tables, ranging from 345- through 700-kV designs. These new design curves are included in a design book now being published by EEI, and should facilitate prediction of lightning performance on many new EHV line designs without resorting to digital computer processing.

SHIELDING FAILURES ON EHV LINES

Recent work by Armstrong and Whitehead[2] points out that many flashovers on EHV lines may be the result of shielding failures, wherein lightning gets by the ground wire and contacts the phase conductor directly. Their "Pathfinder Project" should supply badly needed data on this subject after a few more years of operation. In the meantime, Fig. 7 has been suggested[2] for superior shielding performance.

MIDSPAN FLASHOVERS

Concepts of midspan flashover have been undergoing drastic changes in recent years, largely due to the "pipe-pipe gap" investigations of Wagner and Hileman.[3] They have shown that before flashover occurs between a ground wire and a phase conductor, the corona currents become so intense that they retard the voltage build up for several microseconds, thus permitting reflections to arrive from adjacent towers. These reflections largely remove the voltage between ground wire and phase conductor before breakdown is completed. The newest lightning-outage computation programs incorporate this effect, and the

result has been to greatly reduce the computed number of midspan flashovers.

FUTURE LIGHTNING RESEARCH

Areas of lightning research that would greatly benefit the utilities include the following:

1. Shielding-failure research, such as the Pathfinder Project.[2]
2. Obtaining better and more voluminous statistical data on lightning stroke current magnitudes and wave shapes. High-speed spectrographs might be used for this purpose.
3. Better concepts of the relationships between lightning incidence to earth or to lines and the isokeraunic level in the same vicinity. Atmospheric triangulation techniques and/or cloud-to-ground stroke counters will likely be employed.

REFERENCES

1. F. A. Fisher, J. G. Anderson, and J. H. Hagenguth, "Determination of Lightning Response of Transmission Lines by Means of Geometrical Models," AIEE Trans., pt. III-B (Power Apparatus and Systems), vol. 78, 1959 (February 1960 section), pp. 1725-1734.
2. H. R. Armstrong and E. R. Whitehead, "Field and Analytical Studies of Transmission-Line Shielding," IEEE Trans. Paper 31 PP 67-103, presented at the IEEE Winter Power Meeting, New York City, February 1, 1967.
3. C. F. Wagner, "Application of Predischarge Currents of Parallel Electrode Gaps," IEEE Trans. on Power Apparatus and Systems, vol. 83, Sept. 1964, pp. 931-944.

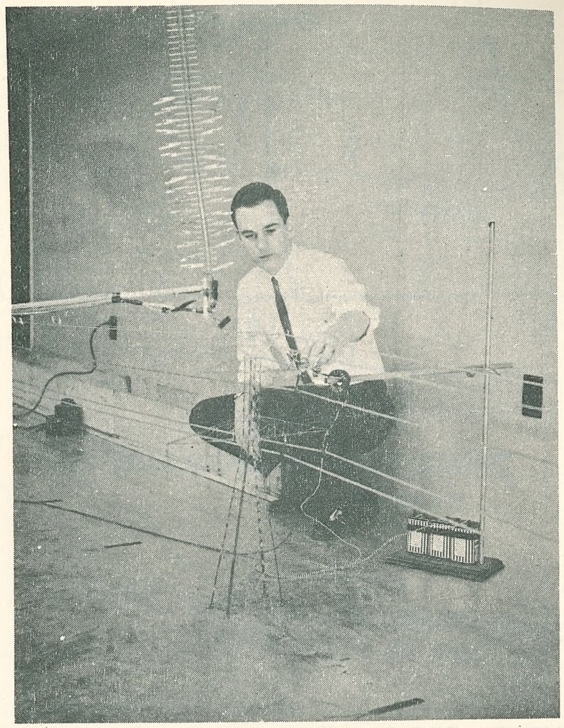

FIGURE 1

50:1 SCALE-MODEL TRANSMISSION TOWER BEING USED TO DETERMINE LIGHTNING PERFORMANCE

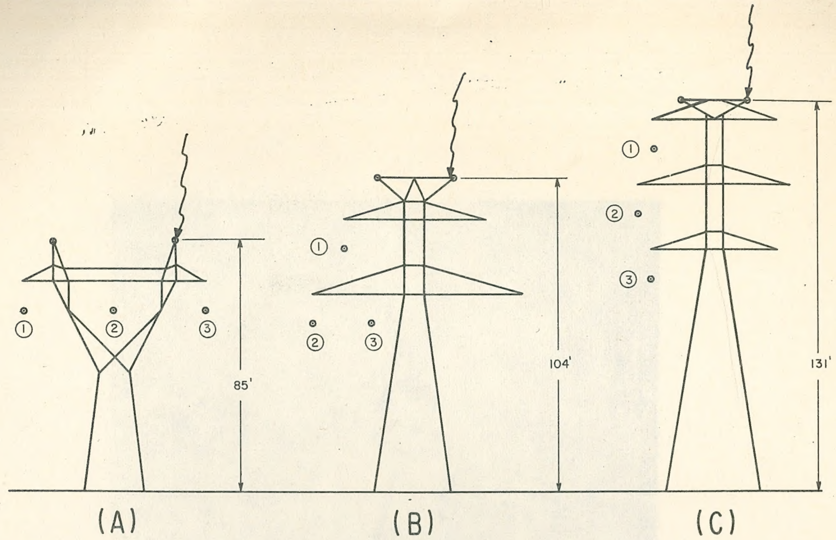

FIGURE 2
TOWERS USED IN COMPARISON TEST

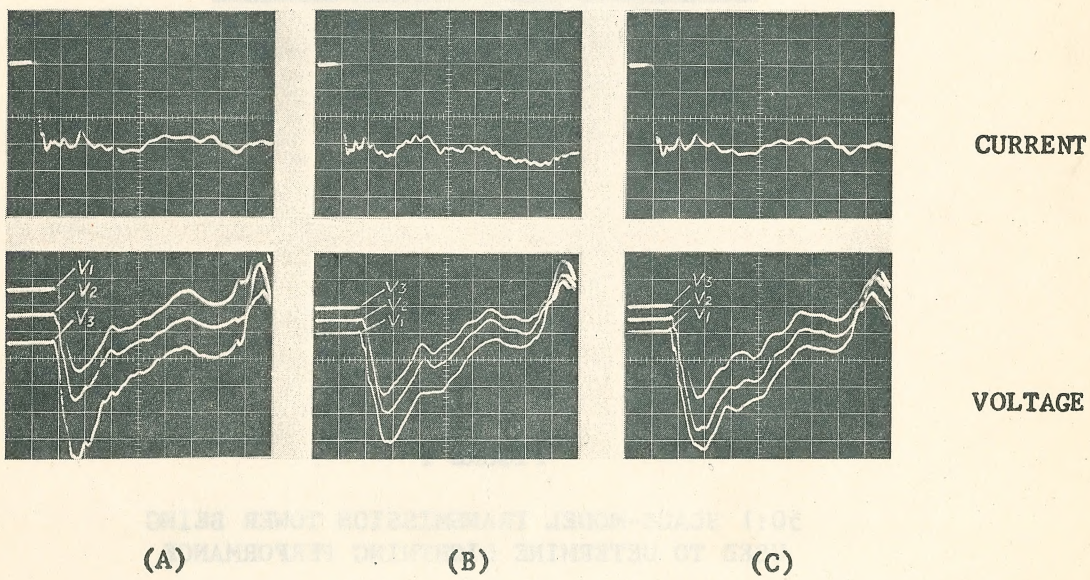

FIGURE 3
INSULATOR VOLTAGES FOR THE THREE
TOWERS SHOWN IN FIGURE 2

Vertical Sensitivity-Current = 0.020A/div
-Voltage = 0.346V/div
Horizontal Sensitivity = 0.25μs/div (Equivalent Full-Scale Time)

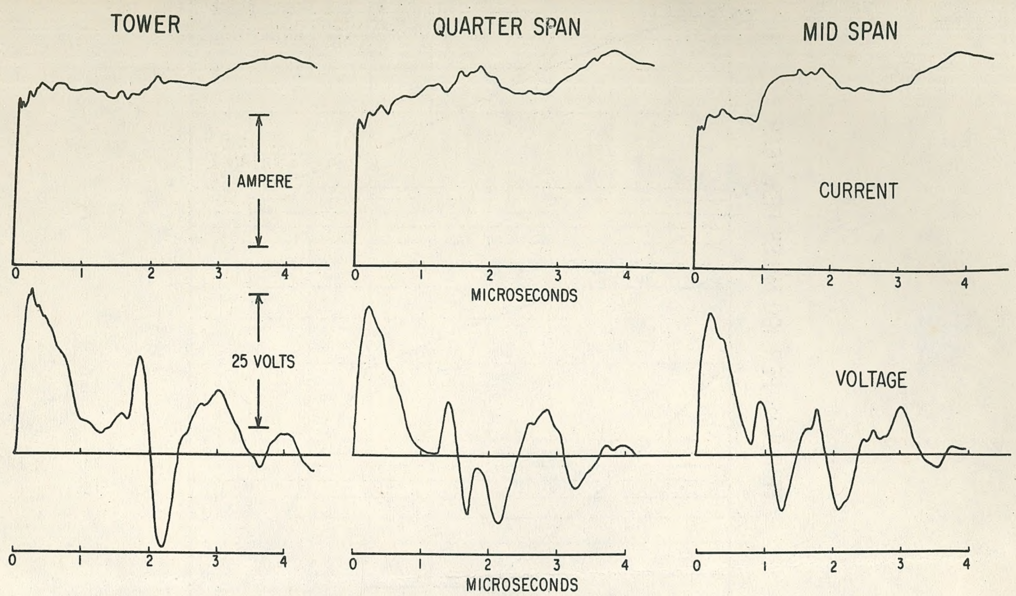

FIGURE 4
INSULATOR VOLTAGES FOR THREE STROKE LOCATIONS
STRUCTURE B OF FIG. 2

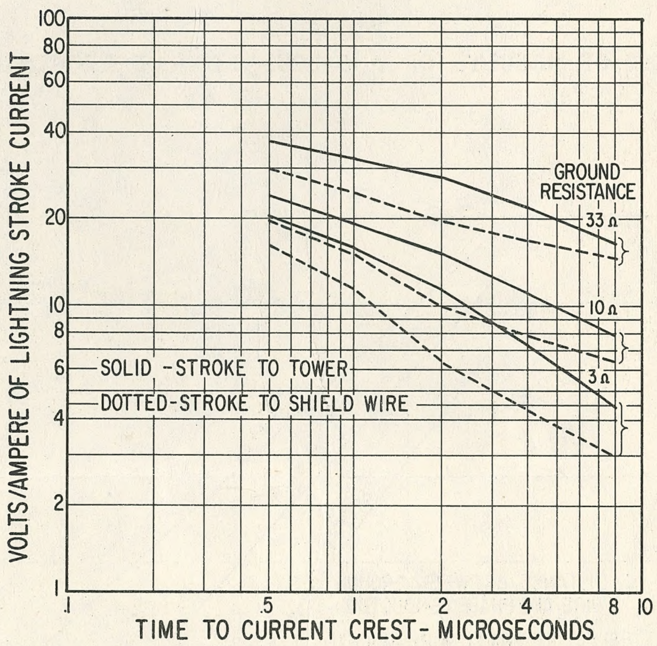

FIGURE 5
CALCULATED RESPONSE TO OTHER CURRENT WAVESHAPES
STRUCTURE B
MAXIMUM VOLTAGES IN ANY PHASE

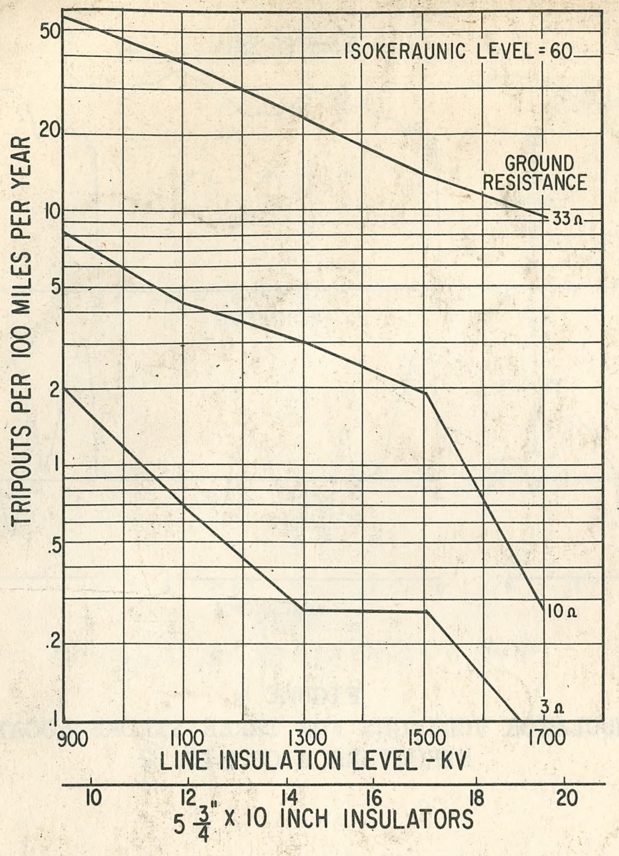

FIGURE 6

TYPICAL FORMAT OF RESULTS OF A CALCULATION OF LIGHTNING PERFORMANCE

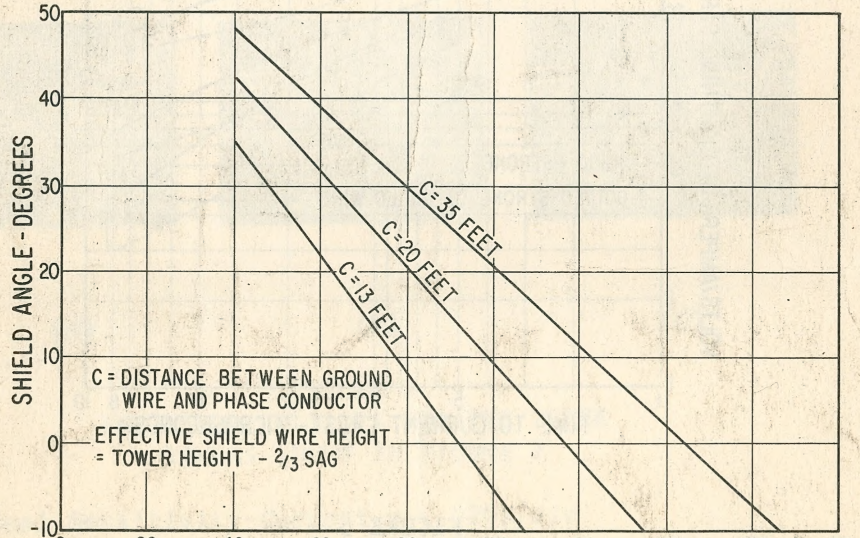

FIGURE 7

SUGGESTED SHIELDING ANGLES OF EHV LINES